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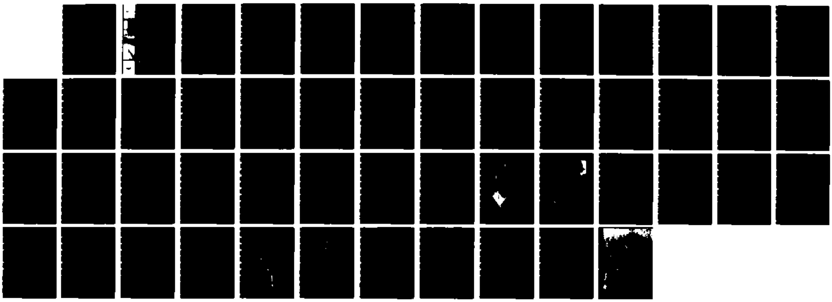

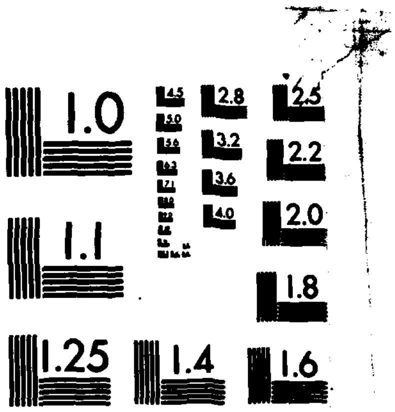
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BREAKAGE OF CONCRETE ARMOR UNITS; SURVEY OF EXISTING CORPS STRUCTURES

by

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By means of a questionnaire and literature review, a survey of existing Corps structures using concrete armor units was conducted. Nine structures were found to exist that use either one or a combination of the following concrete armor units: dolosse, tetrapods, tribars, and quadripods. Both reinforced and unreinforced units have been used; and based on the data compiled in this survey, no statement can be made as to the advantage or

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disadvantage of using steel reinforcement in concrete armor units. Both construction breakage and storm breakage have been cited as the major causes of existing concrete armor unit breakage. Of the nine structures surveyed, none were reported to be in danger of failing due to the existing breakage; but several structures are being closely observed to see what effect, if any, the existing or additional armor unit breakage will have on the overall stability of the structures.

Preface

The survey reported herein was authorized by the Office, Chief of Engineers (OCE), U. S. Army, under Civil Works Research Work Unit Number 31563, "Effect of Broken Armor Units on Breakwater Stability." Funds were provided through the Coastal Engineering Research Area under the field managership of the U. S. Army Coastal Engineering Research Center and OCE Technical Monitor, Mr. J. Lockhart.

The survey was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) during the period June 1980 to February 1981 under the general direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Dr. R. W. Whalin, former Chief of the Wave Dynamics Division. The Wave Dynamics Division and its personnel were transferred to the Coastal Engineering Research Center (CERC) of WES on 1 July 1983 under the direction of Dr. Whalin, Chief of CERC. The survey was conducted by Mr. D. D. Davidson, Chief of the Wave Research Branch (WRB), and Mr. D. G. Markle, Hydraulic Research Engineer, WRB. This report was prepared by Messrs. Markle and Davidson.

The survey was carried out by means of questionnaires, field trips, literature reviews, conferences, and telephone conversations. Unless otherwise noted, any changes to the prototype structures subsequent to February 1981 are not included.

Commanders and Directors of WES during the conduct of this survey and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

Contents

	Page
Preface	1
Conversion Factors, U.S. Customary to Metric (SI) Units of Measurement	3
Introduction	4
Background	4
Survey Methods	4
Questionnaire Responses	5
Summary of Existing Corps Structures Using Concrete Armor Units	5
San Francisco District	5
Crescent City Harbor, California	5
Humboldt Bay, California	6
Santa Cruz Harbor, California	7
Honolulu District	7
Pohoiki Bay, Hawaii, Hawaii	7
Kahului Harbor, Maui, Hawaii	7
Waianae Small Boat Harbor, Oahu, Hawaii	9
Nawiliwili Harbor, Kauai, Hawaii	10
Philadelphia District	10
Manasquan Inlet, New Jersey	10
Buffalo District	11
Cleveland Harbor, Ohio	11
Discussion	12
Conclusions and Recommendations	14
References	15
Tables 1-11	
Plates 1-12	
Appendix A: Questionnaire	A1

Conversion Factors, U.S. Customary to Metric (SI) Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	0.4047	hectares
feet	0.3048	metres
miles (U. S. nautical)	1.852	kilometres
miles (U. S. statute)	1.609344	kilometres
pounds (force)	4.448222	newtons
square feet	0.09290304	square metres
tons (2,000 lb, force)	8896.443353	newtons

BREAKAGE OF CONCRETE ARMOR UNITS
SURVEY OF EXISTING CORPS STRUCTURES

Introduction

Background

1. The survey presented herein is a part of the effort conducted under the Corps of Engineers Research and Development Program, Coastal Engineering Field of Endeavor, Work Unit Number 31563, entitled "Effect of Broken Armor Units on Breakwater Stability." This research was conducted by the Wave Dynamics Division of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES). The objectives were to determine the effect of broken concrete armor units (dolosse) on breakwater stability against wave attack and to establish criteria by which more acceptable decisions can be made as to when maintenance and rehabilitation should be initiated. No criteria presently exist that indicate how many and to what extent broken concrete armor units affect the stability of rubble-mound structures. The work conducted consisted of both hydraulic model tests of rubble-mound breakwater trunk sections protected with dolosse and a survey of armor unit breakage that has occurred on existing Corps structures protected with concrete armor units. The model tests of dolosse on a 1V-on-1.5H breakwater slope have been completed and a draft report is being prepared. The survey of existing Corps structures has been completed and is addressed herein.

Survey methods

2. The survey of existing Corps structures was accomplished by field trips, letters, conferences, telephone conversations, and questionnaires. The questionnaire, prepared at WES, was distributed by the Office of the Chief of Engineers (OCE) to the Division and District offices listed in Table 1 by letter dated 20 August 1980. A copy of the questionnaire (and the information requested therein) is given in Appendix A. The survey was restricted to Corps structures because their design, construction techniques, and quality control are generally more uniform than non-Corps projects; and access to more detailed cause-and-effect data was available. While data from non-Corps projects would be valuable for learning purposes, it was decided that efforts to collect first-hand data world-wide (particularly in light of the uncertainties that go with such data) were not warranted under this study.

Questionnaire responses

3. Four of the offices receiving the questionnaire had existing Corps structures with concrete armor units. Three of the Districts responded on either proposed structures, non-Corps structures, or structures that did not use concrete armor units. These three responses along with the remaining District responses, which stated they had no existing Corps structures using concrete armor units, were classified as negative replies. Table 1 shows the type of response, either positive or negative, that was received from each of the District and/or Division offices. Since the purpose of this survey was to look at existing Corps structures using concrete armor units, only the data from the positive responses were incorporated into this report. As in most surveys, information on all the items requested was not available for any one project. Except for Crescent City Harbor, California, and Cleveland Harbor, Ohio, where more recent survey reports were available (August 1982 and May 1982, respectively), all the information contained herein was extracted from either the 1980 questionnaire responses, cited references, or verbal communication with various District and Division personnel.

Summary of Existing Corps Structures Using Concrete Armor Units

San Francisco District

4. Crescent City Harbor, California, is located on the Pacific coast about 17 miles* south of the Oregon-California border (Plate 1). The existing outer breakwater is 4,670 ft in length. The main stem and easterly extension (dogleg) of the breakwater are approximately 3,670 and 1,000 ft in length, respectively. The original project did not call for the dogleg but intended for the main stem of the breakwater to extend out to Round Rock. The main stem of the original breakwater, beyond sta 37+00, sustained severe damage and was reconstructed on two occasions. Finally, this portion of the main stem was abandoned and the 1,000-ft dogleg referred to above was added. Two-dimensional stability tests were conducted of the tetrapod breakwater designs proposed for the trunk portion of the 1,000-ft dogleg (Hudson and

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

Jackson 1955 and 1956). In 1957, 1,836 25-ton, unreinforced tetrapods were placed on the sea-side slope from sta 41+20 to the end of the dogleg (sta 46+70) and 140 25-ton, unreinforced tetrapods were stockpiled on the sea-side slope of the first 200 ft of the dogleg, adjacent to the main stem (sta 37+00 to 39+00). Model tests were not conducted for the severe breaking wave action that occurs around the elbow of the breakwater, and as of 1975, approximately 70 tetrapods placed in this area had been broken. To date, only three tetrapods placed on the last 550 ft (sta 41+20 to 46+70) of the dogleg have been reported broken. In 1974, 246 40-ton, unreinforced dolosse were placed on the sea-side slope of the last 230 ft of the breakwater's main stem (sta 34+70 to 37+00). Although there is some question as to the exact number of dolosse broken, a maximum number of 70 units has been reported (Edmisten 1982). Of this number, it is certain 22 were broken during placement and/or during storm conditions that occurred while construction was being completed. These 22 units were not removed from the structure. Various portions of the breakwater including the deteriorated tetrapod area (sta 37+00 to 39+00) were repaired with armor stone in 1979. This work together with the prior construction history is summarized in Table 2. Even though the dolos breakage reported is relatively high (28.5 percent), no immediate repair of the dolos area was contemplated after the August 1982 survey. Although the breakwater is in relatively good condition, the surveillance of existing and new armor unit breakage should be continued.

5. Humboldt Bay, California, is located on the Pacific coast of northern California. The city of Eureka, about 280 miles north of San Francisco and about 80 miles south of Crescent City, California, is located on the northwest shore of Humboldt Bay (Plate 2). The Humboldt Bay entrance channel is protected by two rubble-mound jetties. Construction of the parallel north and south jetties, 4,500 and 5,100 ft long, respectively, was initiated in 1889 and completed in 1899. The original jetty construction was rubble-mound armor stone. Severe damage to the heads and portions of the trunks has required numerous rehabilitations and reconstructions of both jetties. Between 1911 and 1970, parapet walls, concrete caps, 20- and 100-ton concrete blocks, concrete monoliths, armor stone, and 12-ton tetrahedrons have been utilized on both jetties in an effort to stabilize the structures. Table 3 shows details of the construction history. The latest rehabilitation work, 1971 to 1972, consisted of rebuilding the concrete monoliths on both the north

and south jetty heads. In addition to this, two layers of dolosse were placed around the heads and tapered into the trunks of both jetties approximately 400 ft behind the heads. This repair work was model-tested (Davidson 1971). To date, 12 dolosse have been reported broken on the north jetty and 22 broken on the south jetty (Table 3). Five of the total number of broken dolosse were reported to have been left on the structure during construction. In any case, almost all of the breakage reported occurred in the first year after construction. At this time, the structure does not appear to have any serious stability problems but it should be closely monitored for possible future breakage.

6. Santa Cruz Harbor, California, is located on the northern end of Monterey Bay at the city of Santa Cruz, California. This area lies about 65 miles south of the entrance to San Francisco Bay (Plate 3). The 850-ft and 1,125-ft east and west jetties, respectively, were constructed in 1963 to protect the entrance channel and harbor from storm waves. The outer 400 ft of the west jetty was constructed with 28-ton, unreinforced quadripods while the remainder of the jetties were constructed using armor stone. Table 4 contains more information on construction history and design conditions. Based on available data, the structure has not been exposed to the design storm conditions and due to shoaling seaward of the west jetty, it is unlikely that design wave conditions could reach the armor units. To date, no stability problems or breakage of armor units has been reported.

Honolulu District

7. Pohoiki Bay, Hawaii, Hawaii, is located on the southeast coast of the Island of Hawaii, about 25 miles southeast of Hilo, Hawaii (Plate 4). In 1979, a 90-ft breakwater was constructed to protect an existing boat-launching ramp. The breakwater slopes and head were protected with two layers of 6-ton unreinforced dolosse. The dolosse were placed from the toe of the structure to the concrete rib cap. Of the 210 dolosse placed, 5 were broken and left on the structure during construction. Since its completion, the breakwater has been exposed to the design storm conditions on several occasions, and no dolos breakage or damage to the structure has been observed. Table 5 summarizes available information on the Pohoiki breakwater.

8. Kahului Harbor, Maui, Hawaii, located on the north coast of the Island of Maui (Plate 5), is about 94 miles southeast of Honolulu, Oahu, Hawaii. The harbor is protected by two rubble-mound breakwaters. The

2,766- and 2,315-ft east and west breakwaters, respectively, were completed in 1931. The heads of both breakwaters were severely damaged by storm waves in 1947, 1952, and 1954. In 1956, the breakwater heads were repaired by casting concrete monoliths on the crowns. The slopes of both heads and 250 ft of the west breakwater trunk (sea side only) were protected with a double layer of 33-ton unreinforced tetrapods; a total of 400 units were placed. A major storm in 1958 (approximately 34-ft breaking waves at breakwater heads) breached the trunk of the east breakwater and caused major damage on both heads. Seven of the 33-ton tetrapods were broken; 3 on the sea-side slope of the west breakwater trunk and 4 which were among the 30 units that were displaced off the inside quadrant of the west breakwater head. A few units also were displaced off the east breakwater head, but no breakage of these units was observed. After the 1958 storm, emergency repairs were made on the east breakwater trunk using basalt armor stones, and model tests were initiated at WES (Jackson 1964) to determine the best methods of stabilizing the breakwaters. In 1966, a partial repair of the breakwaters was completed using 35- and 50-ton reinforced tribars. Table 6 gives placement details. It is known that at least two units were broken and left on the structure during the 1966 repair work. Also during the 1966 repair, a concrete rib cap was added to the crest of the east breakwater trunk. In 1969, 260 19-ton reinforced tribars and a concrete rib cap were added to the west breakwater trunk. This repair work was shoreward of the 33-ton tetrapod area. This provided a partial repair of damages accrued by the structure during the storm of December 1967. None of the 19-ton tribars used in the 1969 repair were broken during construction. In November 1970, high storm waves dislodged 25 of the shoreward end 19-ton tribars and moved them toward the root of the west breakwater. Three units were reported broken during this event. Repair of the west breakwater trunk was initiated again in 1973 using 19- and 35-ton reinforced tribars; no construction breakage occurred. Table 6 gives the details of number of units and areas where they were placed. It was noted in the 1975 aerial photographs that a total of nine and four 33-ton tetrapods were broken on the west and east breakwaters, respectively. A 1977 repair of the west breakwater included placing 30- and 20-ton reinforced dolosse over the damaged 33-ton tetrapod areas (Table 6). One of the two dolosse units broken during construction was left in place. Thirty-, twenty-, and six-ton dolosse were used in the 1977 rehabilitation of the east breakwater; placement details are

given in Table 6. The 6-ton dolosse were the only unreinforced units used in the repair work. During transporting and placement of the 6-ton dolos units, five units were broken. This was the only construction breakage that occurred in the 1977 repair of the east breakwater and these units were either not used or were removed from the structure. On 28 March 1979, a survey was made of the east and west breakwaters to determine the amount of observable breakage. Table 6, item 6, lists all observed armor unit breakage to date. This breakage has not had an adverse effect on the functional integrity of the structure.

9. Waianae Small Boat Harbor, Oahu, Hawaii, is located at the town of Waianae on the west coast of the Island of Oahu, approximately 30 miles west of Honolulu, Hawaii (Plate 6). Model tests of the harbor geometry and stability of the 1 690-ft main breakwater (Plate 6) were conducted (Bottin, Chatham, and Carver 1976) and prototype construction was completed in January 1979. The first 350 ft of the breakwater was constructed using armor stone only; the remainder of the structure was constructed with a double layer of 2-ton unreinforced dolosse on the sea-side slope and around the breakwater head. Plate 6 and Table 7 contain further details on the breakwater's construction and design. Of the 6,633 dolosse placed 47 were broken and left on the structure during construction. To date, a total of 170 dolosse (including the 47 mentioned above) have been found broken and remain on the structure. Most of the postconstruction breakage occurred in the year following construction. During a field inspection of the breakwater in June 1980, it appeared that an unusually large number of the first-layer dolosse had been placed with their vertical fluke downslope. Extensive stability tests conducted with dolos armor units (Carver and Davidson 1977) have indicated that pattern placement tends to reduce the stability of dolosse. Also, several areas of the sea-side slope on the Waianae breakwater appear to be considerably steeper than the 1V-on-2H slope for which the structure was originally designed. These two factors may have played a significant role in the dolos breakage that has occurred since the construction was completed. The breakage has caused no obvious stability problem to date, but the structure should be closely monitored to see the long-term effects of the existing or future breakage that may occur.

10. Nawiliwili Harbor, Kauai, Hawaii, is located on the southeast coast of the Island of Kauai, about 100 nautical miles northwest of Honolulu, Hawaii

(Plate 7). Construction of the 2,150-ft rubble-mound breakwater was completed in 1930. Severe storms in 1954, 1956, and 1957 severely damaged the breakwater and model tests were conducted in 1958 (Jackson, Hudson, and Housley 1960) to determine the best method of rebuilding the head and strengthening about 500 ft of the seaward end of the breakwater. In 1959, the head and seaward 500 ft of the sea-side slope of the trunk were rehabilitated with 17.8-ton tribars and a concrete cap was poured on the crest of the breakwater. Of the 598 tribars placed, 351 were reinforced. One layer of tribars was uniformly placed on the trunk while two layers of random-placed tribars were used on the sea-side slope of the head. A survey of the breakwater in 1975 found major deterioration of about 1,000 ft of the armor-stone trunk and several slumped areas in the uniformly placed tribars. Further inspection revealed that several of the tribar units (approximately 98) were broken, and at that time, model tests were initiated to determine the best method of rehabilitating the structure (Davidson 1978). The rehabilitation work was completed in October 1977. The toe of the one layer of uniformly placed tribars was overlaid with two layers of 11-ton unreinforced dolosse (485 dolosse). The dolos coverage extended from the toe of the slope to approximately +5.0 ft mllw. For 300 ft shoreward of the tribar area, the sea-side slope of the trunk was rehabilitated with two layers of the 11-ton dolosse; 449 dolosse were placed in this area from the toe to the crown of the structure. Thirteen of the dolosse were broken during placement, but these were removed from the structure. No further stability problems or breakage has been observed since the 1977 rehabilitation work and the overall structural integrity of the breakwater appears to be good. Table 8 summarizes construction history, design conditions, and breakage.

Philadelphia District

11. Manasquan Inlet, New Jersey, is located on the Atlantic coast of New Jersey about 26 miles south of Sandy Hook in the boroughs of Manasquan and Point Pleasant Beach (Plate 8). The inlet forms the mouth of the Manasquan River and the northernmost end of the New Jersey Intracoastal Waterway. In 1880, the previously unnavigable inlet was dredged to provide access to a safe harbor for small vessels navigating along the coast. At the same time, sand-filled timber jetties were constructed out to 120 ft beyond the low-water line. The jetties proved to be ineffective in maintaining an open channel and no maintenance was provided. By 1887, the inlet was totally blocked by sand.

In 1930, a 1,230-ft north jetty and a 1,030-ft south jetty were authorized. Both jetties were of riprap (rock) construction. Although the size of stone used is uncertain, the maintenance history (details not available) shows that the original and all subsequent repair and replacement stone have been inadequate. A reconnaissance in early 1977 found that the outer portion of both jetties had been destroyed, and the sand accumulation in the inlet was accelerating due to the damaged south jetty. A rehabilitation of the south jetty was carried out in 1980. A portion of the rehabilitation used reinforced 16-ton dolos armor units. Plate 8 and Table 9 contain details on the dolos placement and a summary of other available data on the jetties. Four dolosse were cracked while temporarily placed on the jetty and inadequately interlocked. These units were repaired with a pressure-injected epoxy grout and placed on the structure for observations of effectiveness of this type of grout repair. The structure has not been exposed to the design storm conditions, and no dolos breakage has been observed since the rehabilitation was completed.

Buffalo District

12. Cleveland Harbor, Ohio, is located on the southern shore of Lake Erie at Cleveland, Ohio (Plate 9). Cleveland is located about 110 miles east of Toledo, Ohio, and about 191 miles west of Buffalo, New York. The harbor is protected by a 20,970-ft east breakwater, 6,048-ft west breakwater, and two 1,250-ft arrowhead breakwaters. The arrowhead breakwaters are connected to the east and west breakwaters at the main entrance to the harbor (Plate 9). The westerly 3,000 ft of the east breakwater is composed of a timber crib, constructed from 1887-1900, and a stone superstructure, constructed from 1917-1926. The remaining 17,970 ft of the east breakwater was constructed from 1903-1915. This portion of the breakwater is a rubble-mound structure with a keyed and fitted system of special-shaped armor stone. Using construction similar to the original work, repairs were made on the east breakwater in the years 1927, 1928, 1930, 1932-40, and 1946-78. During 1980, the eastern 4,400 ft of the east breakwater was rehabilitated (Plate 10). Two layers of 2-ton unreinforced dolosse were placed on the lakeside of the trunk and around the head (Plates 11 and 12, respectively); 29,700 dolosse were placed with a concentration of 161 dolosse per 25 lin ft of the breakwater. Breakage of several dolosse occurred during the construction period and it was suspected that some of these might have been due to poor quality concrete. Prior to

completion of construction, but on a completed portion of the rehabilitation, 22 units were broken during a June 1980 storm. All units that were found broken after the storm were removed from the structure. Final construction on the dolos section was completed in November 1980, at which time a formal monitoring program to show armor unit movement and breakage on the rehabilitated portion of the project was initiated. During the next year (primary period of consolidation and adjustment) randomly located breakage continued until November 1981 when the total number of broken dolosse observed was 329 (1.1 percent of the units placed). No adverse effect on the functional stability of the structure was noted during this time. On 6 April 1982, a particularly severe storm (hindcast waves of 12 ft in height) occurred simultaneously with the highest lake level (+6.1 ft low water datum) ever recorded and caused damage to the rehabilitated dolos section. Although there was some displacement of dolosse over the crest of the trunk section, the primary damage was localized on the tip of the head section where a hole about 20 ft in diameter at the armor surface penetrated to the original stone. The number of units broken due to displacement from the damage hole is not known, but total breakage on the entire dolos section after the April 1982 storm was reported as 487 or 1.6 percent of the units placed. A diver's survey indicated that the broken dolosse are generally in a zone 4 to 6 ft above and below the water level. The head section was repaired in September 1982 by placing approximately 200 dolosse in the localized damage area. The trunk section is not being repaired and does not appear to have any serious stability problems. Annual and/or poststorm breakwater surveys should be continued to see if the existing or any additional dolos breakage begins to cause stability problems. Table 10 summarizes available information on the Cleveland Harbor east breakwater.

Discussion

13. Only three of the nine existing Corps structures with concrete armor units were originally constructed using molded units (Santa Cruz, Pohoiki, and Waianae). The other six structures are old armor-stone breakwaters or jetties that have been rehabilitated with one or more sizes or types of concrete armor units. Of the nine structures discussed, only two have accrued any significant amount of known armor unit breakage, and even these

appear to have specific reasons for the breakage. All of the projects incurred breakage for one reason or another, but most of the breakage was less than 3 percent and has not had an adverse effect on the stability of the structures. Table 11 summarizes the breakage on each project. One of the two projects with significant breakage (Nawiliwili) had been model-tested for hydraulic characteristics and one had not (Crescent City: the main tetrapod portion of this breakwater was model-tested, but the areas where subsequent dolos and tetrapod breakage occurred were not).

14. When the initial model tests (Jackson, Hudson, and Housley 1960) were conducted for the tribar rehabilitation portion of the Nawiliwili Breakwater, it was recommended that a row of large armor stone be placed along the breakwater toe to serve as a buttress for the tribars. Based on U. S. Army Engineer Division, Pacific Ocean, records, this was not done during the prototype rehabilitation. It cannot be stated conclusively, but this very well could have been part of the reason for the slippage and breakage that occurred in the one-layer tribar area.

15. During addition of the 1,000-ft dogleg at Crescent City in 1957, 140 tetrapods were not needed to complete the construction on the outer portion of the dogleg. Since it was already evident that the elbow area was receiving severe wave action due to the wave tripping action produced by the remnants of the damaged breakwater extension toward Round Rock, the excess units were stockpiled in a noncoherent manner on the sea-side slope of the dogleg adjacent to the main stem (about sta 37+00 to 39+00). Unlike the end of the dogleg, model tests were not conducted to check the adequacy of the 25-ton tetrapods to withstand the severe breaking wave action that occurs in this area; thus it is not surprising that the tetrapods in this area have been subjected to high displacement and movement which would result in significant breakage and erosion.

16. At Crescent City, 22 of the 70 dolosse units reported broken were broken prior to completion of construction. Sixteen of the units were broken in a storm that occurred during construction when two rows of individual toe units had been placed ahead of the main body of dolosse. Six additional dolosse were reported broken immediately after construction was completed and 48 units have subsequently broken. The fact that the original breakage was not removed and that the dolos section does not extend to the ocean bottom adds to the potential instability of this section.

17. Recorded data of actual wave heights to which the various structures have been exposed are very limited. In most instances, the probability of past exposures to design conditions is based on recorded visual observations or on the overall magnitude of the storms. In most cases, the actual conditions to which the structures have been exposed are unknown. All armor unit breakage data are based on District and/or Division onsite inspections of the existing conditions above water. In most cases, the degree of armor unit breakage existing below water is unknown. Some diver inspections at Cleveland Harbor indicate that the breakage below the waterline is less than that observed above water but no definite data are known. Therefore the statements contained herein on observed wave conditions to which the structures have been exposed and the amount of breakage that exists are based solely on the questionnaire responses and/or verbal communication with various Division and District personnel.

Conclusions and Recommendations

18. Based on the prototype survey data reported herein, general conclusions are as follows:

a. Since no firm guidance is available regarding under what conditions, the amount, or the type of reinforcement that should be used in concrete armor units, sporadic use of both normal and fiber steel reinforcement has occurred. This random usage of reinforcement and the mixing of reinforced and nonreinforced units on various structures make it difficult if not impossible to quantify the benefits or problems derived from use of reinforcing.

b. Where good sound professional engineering practices were followed, prototype breakage has been random and has not exceeded about 3 percent of the total number of units placed. This amount of breakage does not appear to have had any effects on the overall functional and structural integrities of the breakwaters and jetties.

19. Until the dynamic forces encountered by prototype concrete armor units are better understood, no standard design guidance can be established. Thus it is recommended that research efforts be concentrated on determining the dynamic and static loadings of individual concrete armor units due to wave action and/or that the structural strength characteristics of concrete units be modeled to determine the limits of their structural integrity.

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Table 1

Distribution of and Response to the "Prototype Breakage of Breakwater Armor Units" Questionnaire

Divisions	Districts	Response* Positive	Response* Negative
North Pacific	Seattle		X
	Portland		X
	Alaska		X
South Pacific	San Francisco	X	
	Los Angeles		X
Pacific Ocean	Honolulu	X	
Southwestern	Galveston		X
Lower Mississippi Valley	New Orleans		X
South Atlantic	Mobile		X
	Jacksonville		X
	Savannah		X
	Charleston		X
	Wilmington		X
North Atlantic	Norfolk		X
	Baltimore		X
	Philadelphia	X	
	New York		X
New England			X
North Central	Buffalo	X	
	Detroit		X
	Chicago		X
	St. Paul		X

* Positive response: have existing Corps structures using concrete armor units.
Negative response: have no existing Corps structures using concrete armor units.

Table 2

Outer Breakwater, Crescent City Harbor

Crescent City, California

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1. Division: South Pacific 2. District: San Francisco

3. Construction and Rehabilitation History:

   a. 1930; 3,000-ft main stem of breakwater (sta 0+00 to 30+00); armor stone

   b. 1948; 1,000-ft extension of main stem (sta 30+00 to 40+00); armor stone

   c. 1949; repair of main stem (sta 30+00 to 40+00) and extension of main stem to sta 42+00; armor stone

   d. 1950; repair of main stem (sta 30+00 to 42+00) using armor stone and addition of concrete cap to crown of breakwater except for area between sta 12+34 and 15+34.

   e. 1957; 500 ft of main stem (sta 37+00 to 42+00) was abandoned; addition of 1,000-ft dogleg (sta 37+00 to 46+70); 12-ton stone protection was used from sta 37+00 to 41+20; beginning at sta 41+20, two layers of 25-ton unreinforced tetrapods (1,836 units) were placed on the sea-side slope (model-tested, Hudson and Jackson 1955, 1956) and around the head of the dogleg; 140 of the same size tetrapods were placed on the existing stone armor protection on the sea-side slope of the first 200 ft of the dogleg adjacent to the main stem (sta 37+00 to 39+00). These 140 tetrapods were not placed in coherent two layers, and this area of repair was not model-tested.

   f. 1974; rehabilitation of main stem of breakwater (sta 34+70 to 37+00); two layers of 40-ton unreinforced dolosse (246 units) were placed on the sea-side slope (not model-tested).

   g. 1979; repair of following reaches using 18- to 30-ton stone: sta 19+00 to 20+00, sta 22+00 to 24+00, sta 24+60 to 27+20, sta 28+90 to 29+50, sta 30+50 to 31+00, and sta 37+00 to 41+20; sta 15+50 to 17+50 was repaired using 14- to 25-ton stone (none of the above were model-tested).

4. Design Storm Condition: 21- to 35-ft breaking waves (1-in-100 year occurrence).

5. Maximum Storm Conditions to Which Structure Has Been Exposed: Design conditions.

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date:

   a. 70 of the 140 tetrapods placed at start of dogleg.

   b. 3 of the 1,836 tetrapods placed on outer portion of dogleg.

   c. 70 of the dolosse placed on the main stem; 22 of these were broken during placement and/or by storm conditions that occurred during construction and were left in place.

(Continued)

Table 2 (Concluded)

7. Conclusions: The three broken tetrapods on the end of dogleg have had no obvious detrimental effect on the stability of this area. The 70 broken tetrapods at the start of the dogleg have caused a reduction in the stability of this area of the breakwater; consequently, this was included in the general repairs conducted in 1979. Breakage within the dolos area is relatively high, and obviously, this area should be monitored very closely to determine cause and effect data on future deterioration.

Table 3

North and South Jetties, Humboldt Bay

Eureka, California

1. Division: South Pacific   2. District: San Francisco

3. Construction and Rehabilitation History (Magoon, Sloan, and Shimizu 1976):

   a. 1889-1899; 4,500 ft north jetty and 5,100 ft south jetty; armor stone.

   b. 1911-1915; reconstruction of south jetty; armor stone.

   c. 1915-1916; 1,000-ton concrete monolith added to seaward end of south jetty.

   d. 1915-1925; reconstruction of north jetty, armor stone; 1,050-ton concrete monolith added to seaward end.

   e. 1925-1927; parapet walls and concrete caps were added to the crests of both jetties and mass concrete was poured on channel slopes to stabilize armor stone.

   f. 1930-1958; rehabilitation of both jetties. Mass concrete was poured to fill eroded areas on crests; armor stones were replaced in areas that were breached and washed out. Both 100-ton concrete blocks (number not known) and 12-ton tetrahedrons (number not known) were placed on the heads of both jetties during this time period (not model-tested).

   g. 1960-1963; rehabilitation of both jetties (not model-tested). Trunks were repaired with 12-ton stone; reconstruction of heads using 20-ton concrete blocks to form perimeter of heads and centers were filled with mass concrete; 100-ton concrete blocks (250 total) were placed around the seaward tip of the south jetty head.

   h. 1971-1972; rehabilitation of both jetties (model-tested, Davidson 1971); concrete monoliths were reconstructed; 42-ton dolosse placed around the seaward quadrant of both jetty heads (4 unreinforced, 1,271 steel-reinforced, and 17 steel-fiber-reinforced dolosse on north jetty, and 22 unreinforced and 1,423 steel-reinforced dolosse on south jetty); 43-ton dolosse placed on the shoreward-transition sections of both jetty heads (967 and 1,090 steel-reinforced dolosse placed on north and south jetties, respectively); two layers of dolosse were placed using a concentration of 11 dolosse per 1,000 sq ft of slope.

4. Design Storm Conditions: 16-sec, 40-ft breaking waves.

5. Maximum Storm Conditions to Which Structure Has Been Exposed: No recorded data but design conditions were probable.

(Continued)

Table 3 (Concluded)

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date (Based on 1980 inspection report):

Armor Unit	Number Broken
North Jetty	
42-ton dolosse (steel reinforced)	9
43-ton dolosse (steel reinforced)	3
South Jetty	
42-ton dolosse (unreinforced)	9
42-ton dolosse (steel reinforced)	9
43-ton dolosse (steel reinforced)	4

Of the total breakage observed, about five of these units were reported to have been broken and left on the structure during construction. A majority of the breakage on each jetty head occurred in the first year after construction.

7. Conclusions: Existing dolos breakage does not appear to have reduced the overall stability of the dolos armor layers, but close observation of the structure should be conducted to see if breakage of the dolos units continues to occur.

Table 4

West Jetty, Santa Cruz Harbor

Santa Cruz, California

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1. Division: South Pacific   2. District: San Francisco

3. Construction and Rehabilitation History: (Weymouth and Magoon 1969): Construction completed in 1963; 850-ft armor stone east jetty, and 1,125-ft armor stone and quadripod west jetty; 900 28-ton unreinforced quadripods were placed on the outer 400 ft of the west jetty; two layers of quadripods were placed on sea-side slope of trunk and around the head; quadripods were buttressed against the concrete cap on the crown of the jetty; (design was not model-tested).

4. Design Storm Conditions: 16-sec, 21-ft breaking waves; this 1-in-10-year occurrence design condition would require 25-ton quadripods, but as stated above, 28-ton units were used.

5. Maximum Storm Conditions to Which Structure Has Been Exposed: 12.7-ft waves, December 1968 (maximum height found in available data).

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date: None.

7. Conclusions: Structure has no stability problems, but based on available data, the structure has only been exposed to wave heights that are only slightly greater than one-half of the design wave height.

Table 5

Breakwater, Pohoiki Bay

Hawaii, Hawaii

1. Division: Pacific Ocean
2. District: Honolulu

3. Construction and Rehabilitation History: A 90-ft, dolos-armored breakwater was constructed in 1979. Two layers of 6-ton unreinforced dolosse (210 units) were placed from the toe of the structure to the concrete rib cap on the crest (not model-tested). The dolos protection extended around the entire structure, except for the area where it connected to the shore. Inspection of the final constructed section showed a gap one to two dolos units wide between the rib cap and the upper row of dolos units.

4. Design Storm Conditions: 20-sec, 12-ft breaking waves. This depth-controlled breaking wave condition is expected to occur at least once a year.

5. Maximum Storm Conditions to Which Structure Has Been Exposed: 14-sec, 12-ft breaking waves have reportedly occurred on several occasions since construction was completed.

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date: Five units, all of which were broken and left on the structure during construction.

7. Conclusions: To date the structure has not accrued any obvious damage due to storm waves, and it is felt that the five broken dolosse have not had an adverse effect on the stability of the breakwater. The gap at the top of the dolos units gives potential for dolos displacement and breakage; thus the structure should be observed at frequent intervals to gather as much cause-and-effect data as possible.

Table 6

East and West Breakwaters, Kahului Harbor

Kahului, Maui, Hawaii

1. Division: Pacific Ocean   2. District: Honolulu

3. Construction and Rehabilitation History:

   a. 1931; 2,766-ft east breakwater, and 2,315-ft west breakwater; armor stone.

   b. 1956; repair of breakwater heads and 250 ft of west breakwater trunk; concrete monoliths poured on crest of heads; two layers of 33-ton unreinforced tetrapods (400 units total) were placed on slopes of heads and sea-side slope of west breakwater trunk (not model-tested).

   c. 1958; emergency repair of breach in east breakwater trunk; armor stone.

   d. 1966; repair of both breakwater heads and the first 355 ft shoreward of the east breakwater head; one layer of 35-ton tribars were placed and overlaid with one layer of 50-ton tribars on the inboard quadrants of the breakwater heads; two layers of 35-ton tribars were placed on the sea-side slope of the east breakwater head and buttressed against the concrete rib cap constructed on the crest; 827 and 181 35-ton reinforced tribars placed on east and west breakwaters, respectively; 43 and 173 50-ton reinforced tribars placed on east and west breakwaters, respectively. Except for concrete rib cap, all repair work was model-tested (Jackson 1964).

   e. 1969; repair of west breakwater trunk; two layers of 19-ton reinforced tribars (260 units) were placed on the sea-side slope, shoreward of the tetrapod armor area. A concrete rib cap was added to the crest for buttressing of the tribars (repairs not model-tested).

   f. 1973; repair of west breakwater trunk; the area rehabilitated in 1969 was repaired and extended slightly using eighty 19-ton reinforced tribars; twenty-five 35-ton reinforced tribars were placed adjacent to and on the shoreward end of this area. The acute angle of wave attack that occurs in this area tended to displace the 19-ton tribars shoreward, and the 35-ton tribars were added as a buttress for the smaller units (repairs not model-tested).

   g. 1977; repair of west breakwater head and trunk; 257 30-ton and 291 20-ton reinforced dolosse were placed (two layers over the 33-ton tetrapods) on the sea-side quadrant of the head and sea-side slope of trunk, respectively (not model-tested).

(Continued)

Table 6 (Concluded)

h. 1977; repair of east breakwater head and trunk; 610 30-ton reinforced dolosse were placed in a double layer over the 33-ton tetrapods on the seaward quadrant of the head; 164 20-ton reinforced dolosse were placed in a double layer on the sea-side slope of the trunk beginning at the shoreward end of the 35-ton tribars. Beginning at the point where the 20-ton dolosse ended and extending shoreward, two layers of 6-ton unreinforced dolosse were placed (455 units) on the sea-side slope of the trunk (repairs not model-tested).

4. Design Storm Conditions: 18-sec, 34-ft breaking waves (1-in-25-year occurrence).

5. Maximum Storm Conditions to Which Structure Has Been Exposed: Observed design conditions in 1947 and again in 1954; thereafter, no recorded observations but design conditions were probable.

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date:

Armor Unit	Number Broken
West Breakwater	
33-ton unreinforced tetrapods	9
19-ton reinforced tribars	5
35- and 50-ton reinforced tribars	2
20- and 30-ton reinforced dolosse	14
East Breakwater	
33-ton unreinforced tetrapods	4
35- and 50-ton reinforced tribars	4
6-ton unreinforced dolosse	6
20- and 30-ton reinforced dolosse	2

7. Conclusions: The existing breakage has not had any adverse effect on the functional integrity of the structure; but from the amount of breakage that has occurred, it is apparent that the structure should be surveyed closely after major storm events.

Table 7

Main Breakwater, Waianae Small Boat Harbor

Waianae, Oahu, Hawaii

1. Division: Pacific Ocean 2. District: Honolulu

3. Construction and Rehabilitation History: Construction of the 200-ft stub and 1,690-ft main breakwaters was completed in January 1979. The stub breakwater and first 390 ft of the main breakwater were constructed using armor-stone cover layers. The remaining 1,300 ft of the main breakwater was constructed with two layers of 2-ton unreinforced dolosse (6,633 units) on the sea-side slope of the trunk and around the breakwater head. The crown and harbor-side slope were protected with armor stone (dolos section model-tested, Bottin, Chatham, and Carver 1976).

4. Design Storm Conditions: 16-sec, 11.8-ft breaking waves (1-in-50-year occurrence).

5. Maximum Storm Conditions to Which Structure Has Been Exposed: No storm conditions have been observed.

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date: 170 dolosse found broken of which 47 were broken and left on the structure during construction.

7. Conclusions: To date, the observed breakage does not appear to be having any adverse effect on the stability of the breakwater. The breakwater should be surveyed regularly to see if the existing or any additional armor unit breakage begins to have a detrimental effect on the stability of the dolos armor layers.

Table 8

Breakwater, Nawiliwili Harbor

Nawiliwili, Kauai, Hawaii

1. Division: Pacific Ocean — 2. District: Honolulu

3. Construction and Rehabilitation History:

   a. 1930; 2,150-ft rubble-mound breakwater.

   b. 1959; rehabilitation of head and outer 500 ft of trunk (model-tested, Jackson, Hudson, and Housley 1960); two layers of 17.8-ton tribars random-placed on sea-side slope of head and one layer of 17.8-ton tribars uniformly placed on sea-side slope of trunk; 351 of the 598 tribars placed were reinforced; concrete cap and reinforced concrete posts added to crown of breakwater in rehabilitation area.

   c. 1977; rehabilitation of one layer tribars and 300 ft of trunk shoreward of this area (model-tested, Davidson 1978); 485 11-ton unreinforced dolosse (two layers) were placed from toe to approximately +5.0 ft mllw over one layer tribar area; 449 11-ton unreinforced dolosse (two layers) were placed on the sea-side slope of the trunk for 300 ft shoreward of the tribar area. The dolosse in this area were placed from the toe to the crown of the structure.

4. Design Storm Conditions:

   a. Trunk: 12-sec, 19.4-ft breaking waves (1-in-5-year occurrence).

   b. Head: 15-sec, 24-ft breaking waves (1-in-5-year occurrence).

5. Maximum Storm Conditions to Which Structure Has Been Exposed: 15 to 18 sec, 16-ft waves in March 1957; thereafter, no recorded data but design conditions were probable.

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date: 98 tribars in the one-layer area on sea-side of trunk, 43 above water and 55 below water.

7. Conclusions: Since the 1977 rehabilitation work, no additional stability problems have become apparent.

Table 9

South Jetty, Manasquan Inlet

Point Pleasant, New Jersey

1. Division: North Atlantic   2. District: Philadelphia

3. Construction and Rehabilitation History:

   a. 1880; inlet opened and sand-filled timber jetties constructed out to 120 ft beyond low-water line (not model-tested).

   b. 1881-1887; no maintenance carried out and by 1887 inlet was totally blocked by sand.

   c. 1899; repair of north jetty (not model-tested).

   d. 1930; construction of 1,900 lin ft of steel-sheet-pile bulkheads, 1,230-ft north jetty and 1,030 ft south jetty (not model-tested). Both jetties were rubble-mound structures. Size of armor stone used is uncertain.

   e. 1931-1979; repair work carried out during this time period, but details on work done were not made available.

   f. 1980; rehabilitation of south jetty (not model-tested); 680 16-ton steel-reinforced dolosse were placed on the outer 400 ft of the channel-side slope, around the head, and 50 ft of the beach-side slope. The dolosse were placed from the toe to the crown with a concentration of 23 dolosse per 1,000 sq ft of surface area. The first layer of dolosse was placed with the vertical fluke downslope and random placement was used in the second layer. Further details on the rehabilitation work were not made available.

4. Design Storm Conditions: 13-sec, 25-ft breaking waves (1-in-50-year occurrence).

5. Maximum Storm Conditions to Which Structure Has Been Exposed: No data available.

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date: None.

7. Conclusions: Until the design storm conditions occur, no conclusions can be drawn as to the adequacy of the dolos rehabilitation work.

Table 10

East Breakwater, Cleveland Harbor

Cleveland, Ohio

1. Division: North Central 2. District: Buffalo

3. Construction and Rehabilitation History:

   a. 1887-1900; 3,000 ft of east breakwater; timber crib construction (not model-tested).

   b. 1903-1915; 17,970 ft of east breakwater; keyed and fitted, special-shaped armor stone (not model-tested).

   c. 1917-1926; addition of armor stone to the 3,000 ft of east breakwater previously constructed between 1887 and 1900 (not model-tested).

   d. 1927, 1928, 1930; 1932-34, 1936-40, 1946-1978; repairs made to various reaches of the east breakwater during each of these years; original construction methods were used in making the repairs (not model-tested).

   e. 1980; rehabilitation of 4,400 ft of eastern end of east breakwater (sta 230+00 to 274+00) using 29,500 2-ton unreinforced dolosse. Two layers were placed on the lake side of the trunk and around the head using a placement density of 161 dolosse per 25 lin ft of breakwater (not model-tested).

   f. 1982; repair of head damage (April 1982 storm) using 200 2-ton unreinforced dolosse.

4. Design Storm Conditions: 8.8-sec, 13.4-ft nonbreaking waves; a 1-in-20-year occurrence wave, plus a 10-year maximum monthly mean lake level plus a short-term lake level fluctuation were used resulting in a 1-in-200-year event assuming all events are independent.

5. Maximum Storm Conditions to Which Structure Has Been Exposed: 12-ft waves have been hindcast from April 1982 storm wind data.

6. Concrete Armor Unit Breakage Observed and Remaining on Structure to Date: Most recent survey (May 1982) reported 487 broken dolosse.

7. Conclusions: The overall functional and structural integrities of the dolosse appear to be good, but surveys of the breakwater should be continued to see if the existing or any additional dolos breakage begins to cause stability problems.

Table 11

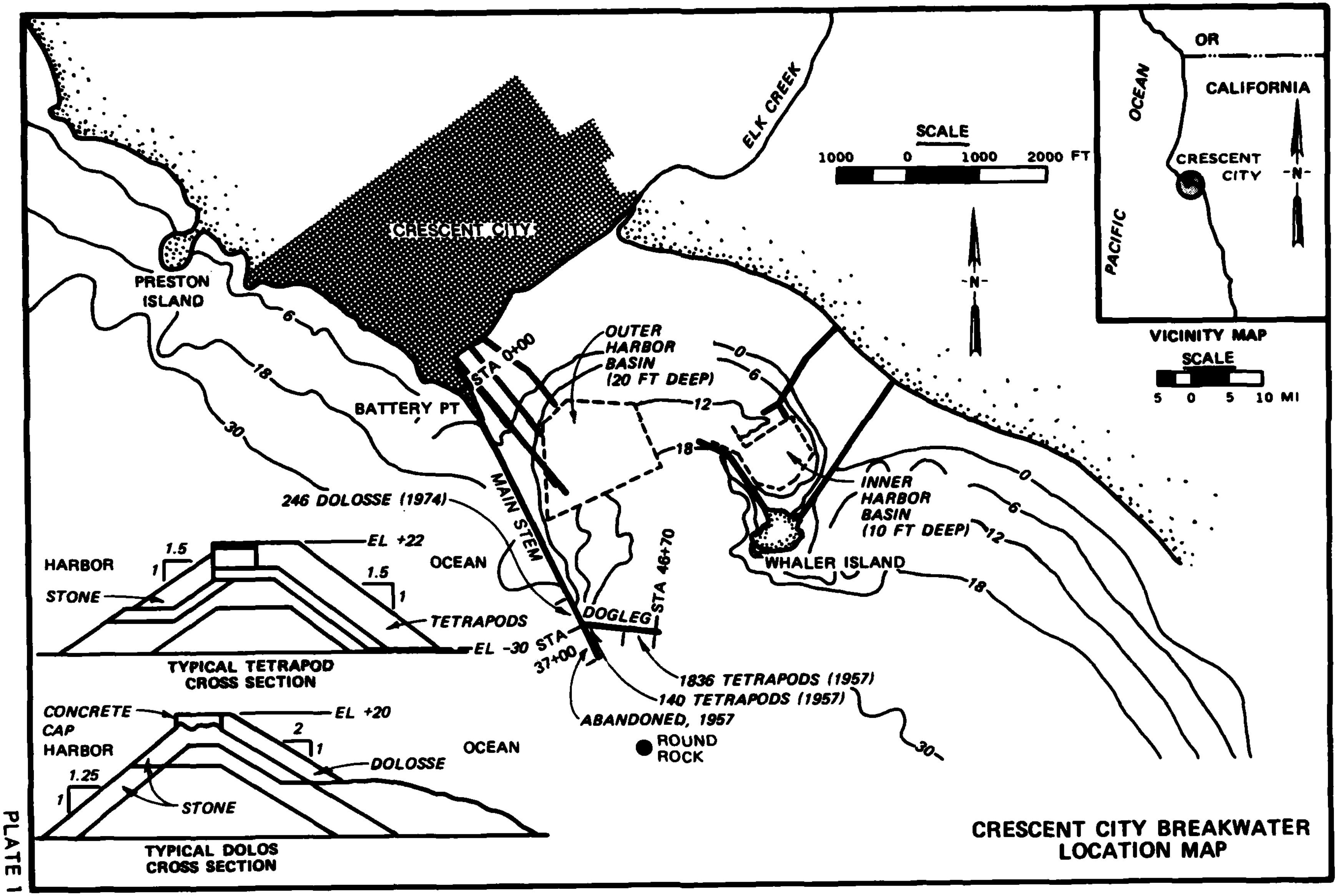
Summary of Armor Unit Breakage Reported in Prototype Survey

Location	Type of Unit and Date of Placement	Armor Unit Size, tons	Was Reinforcement Used?	Total No. of Units Placed	Units Broken to Date No.	Units Broken to Date %	Design Wave Height, ft	Has Structure Witnessed Design Wave?
San Francisco District								
Crescent City Breakwater, Crescent City, Calif.	Tetrapods (1957): Sta 41+20 to 46+70	25	No	1,836	3	0.2	21	Yes
	Tetrapods (1957): Sta 37+00 to 39+00	25	No	140	70	50.0	21	Yes
	Dolosse (1974): Sta 34+70 to 37+100	40	No	246	70	28.5	35	Yes
Humboldt Jetties Eureka, Calif.	Dolosse (1971): South Jetty	42-43	Yes (2,513) No (22)	2,535	22	0.9	40	Probably
	Dolosse (1972): North Jetty	42-43	Yes (2,255) No (4)	2,259	12	0.5	40	Probably
Santa Cruz Jetties Santa Cruz, Calif.	Quadripods (1963): West Jetty	28	No	900	0	0	21	No
Honolulu District								
Pohoiki Breakwater Pohoiki Bay, Hawaii, Hawaii	Dolosse (1979)	6	No	210	5	2.4	12	Yes
Kahului Breakwaters Kahului, Maui, Hawaii	Tetrapods (1956): West Breakwater	33	No	400	9 (13)	3.2	34	Probably
	East Breakwater	33	No		4			
	Tribars (1966): West Breakwater	35 50	Yes Yes	181 173 (354)	2	0.6	34	Probably
	East Breaker	35 50	Yes Yes	827 43 (870)	4	0.4	34	Probably

(Continued)

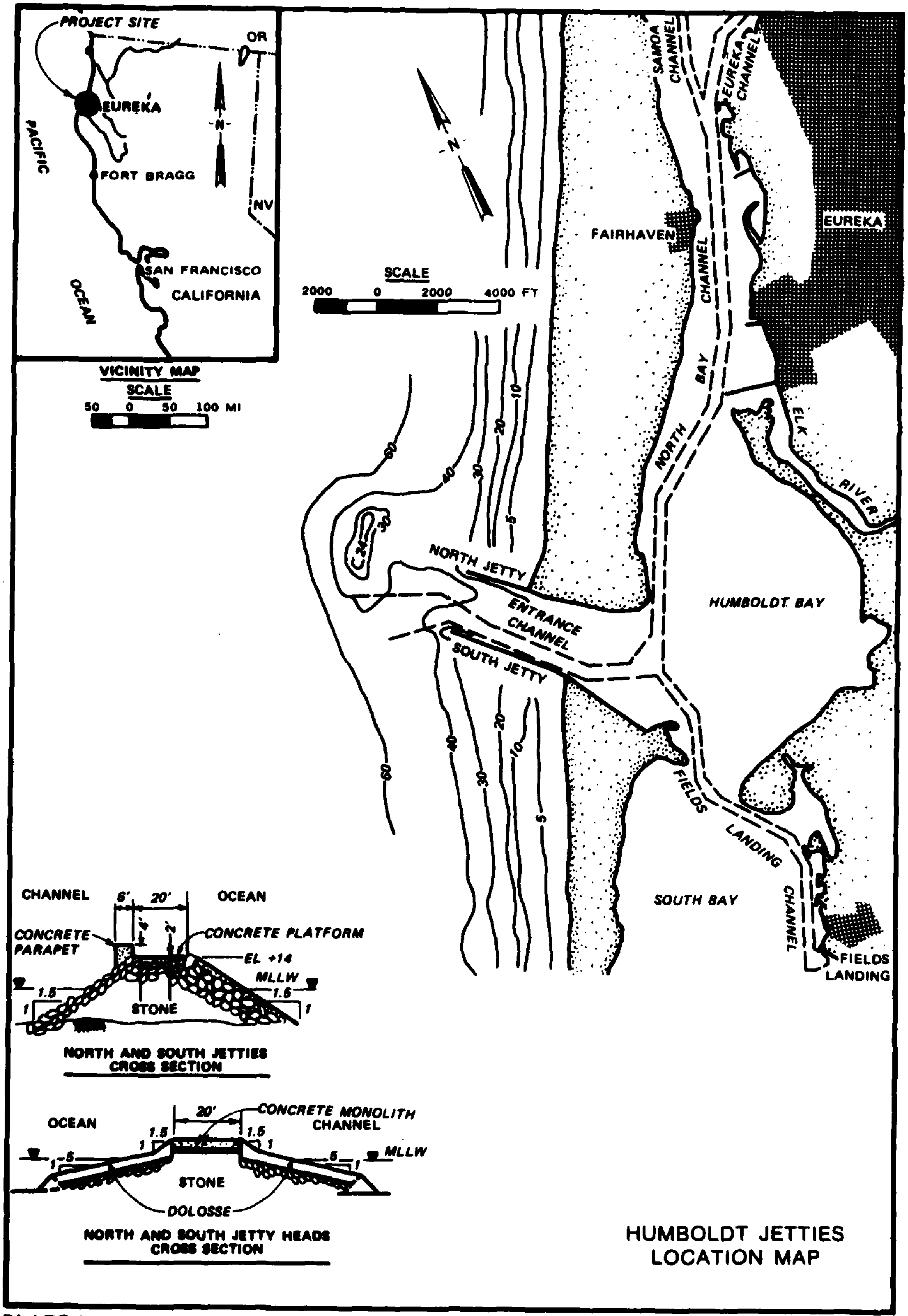
Table 11 (Concluded)

Location	Type of Unit and Date of Placement	Armor Unit Size, tons	Was Reinforcement Used?	Total No. of Units Placed	Units Broken to Date No.	Units Broken to Date %	Design Wave Height, ft	Has Structure Witnessed Design Wave?
Kahului Breakwaters (Cont'd)	Tribars (1969): West Breakwater	19	Yes	260	5	1.9	(Depth-limited)	Probably
	Tribars (1973): West Breakwater	19	Yes	80	0	0	(Depth-limited)	Probably
		35	Yes	25	0	0		
	Dolosse (1977): West Breakwater	20	Yes	291 (548)	14	2.6	(Depth-limited)	Probably
		30	Yes	257				
	East Breakwater	6	No	455	6	1.3	(Depth-(limited)	Probably
		20	Yes	164 (774)	2	0.3		
		30	Yes	610				
Waianae Breakwater Waianae, Oahu, Hawaii	Dolosse (1979)	2	No	6,633	170	2.6	11.8	No
Nawiliwili Breakwater Nawiliwili, Kauai, Hawaii	Tribars (1959): Head	17.8	Yes (351)	351 (598)			24	Probably
	Truck	17.9	No (247)	247			19	Probably
	Dolosse (1977)							
	Trunk	11	No	485	0	0	19	Probably
<u>Philadelphia District</u>								
Manasquan Jetty Point Pleasant, NJ	Dolosse (1980): South Jetty	16	Yes	680	0	0	25.0	Unknown
<u>Buffalo District</u>								
Cleveland Breakwater	Dolosse (1980)	2	No	19,700	487	1.6	13.4	No



CRESCENT CITY BREAKWATER LOCATION MAP

PLATE 1


PROJECT SITE
OR
EUREKA
PACIFIC
OCEAN
FORT BRAGG
NV
SAN FRANCISCO
CALIFORNIA
N
VICINITY MAP
SCALE
50 0 50 100 MI
SCALE
2000 0 2000 4000 FT
SAMOA CHANNEL
EUREKA CHANNEL
EUREKA
FAIRHAVEN
NORTH BAY CHANNEL
ELK RIVER
NORTH JETTY
ENTRANCE CHANNEL
SOUTH JETTY
HUMBOLDT BAY
FIELDS LANDING CHANNEL
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CHANNEL
OCEAN
6'
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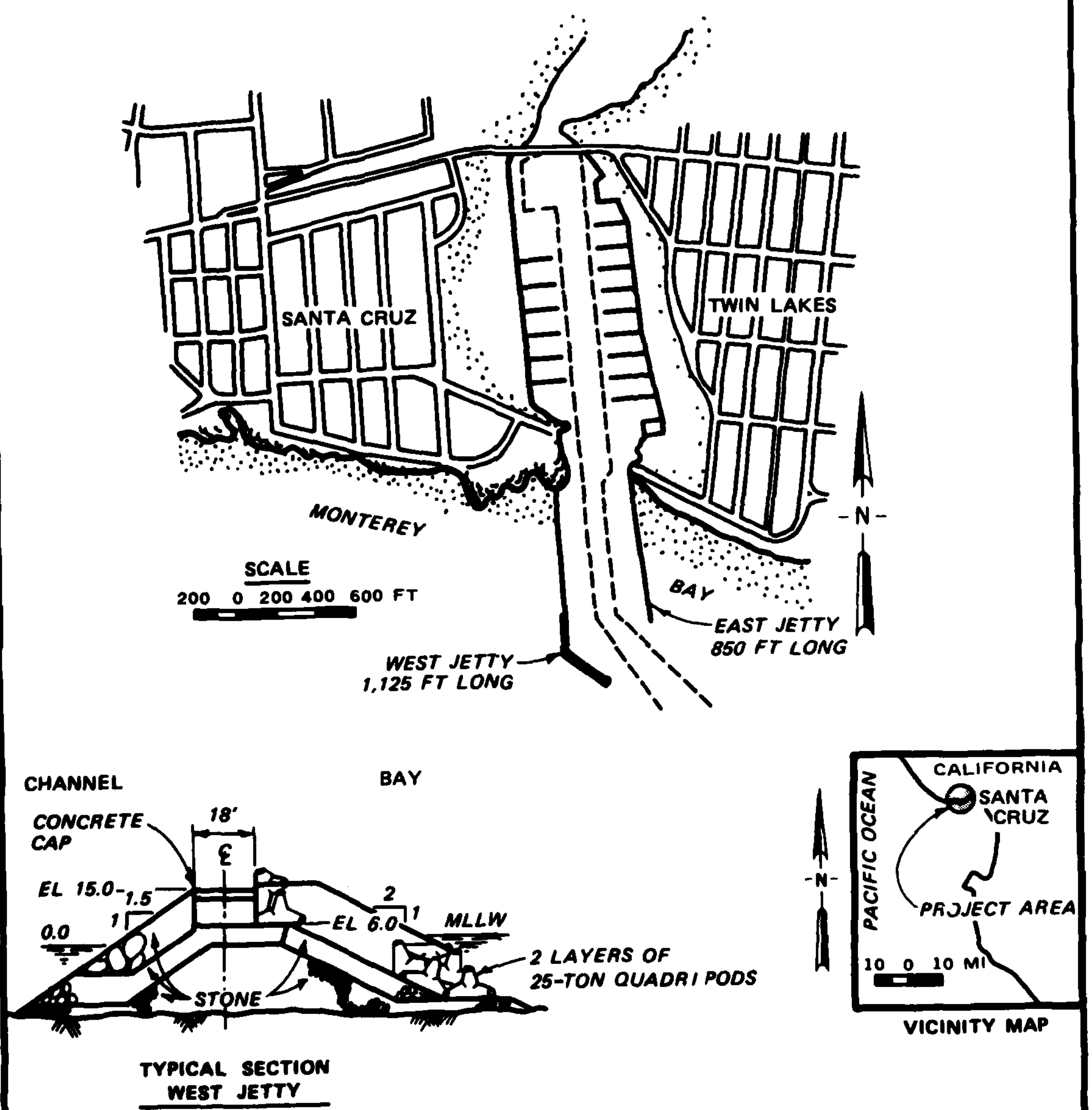
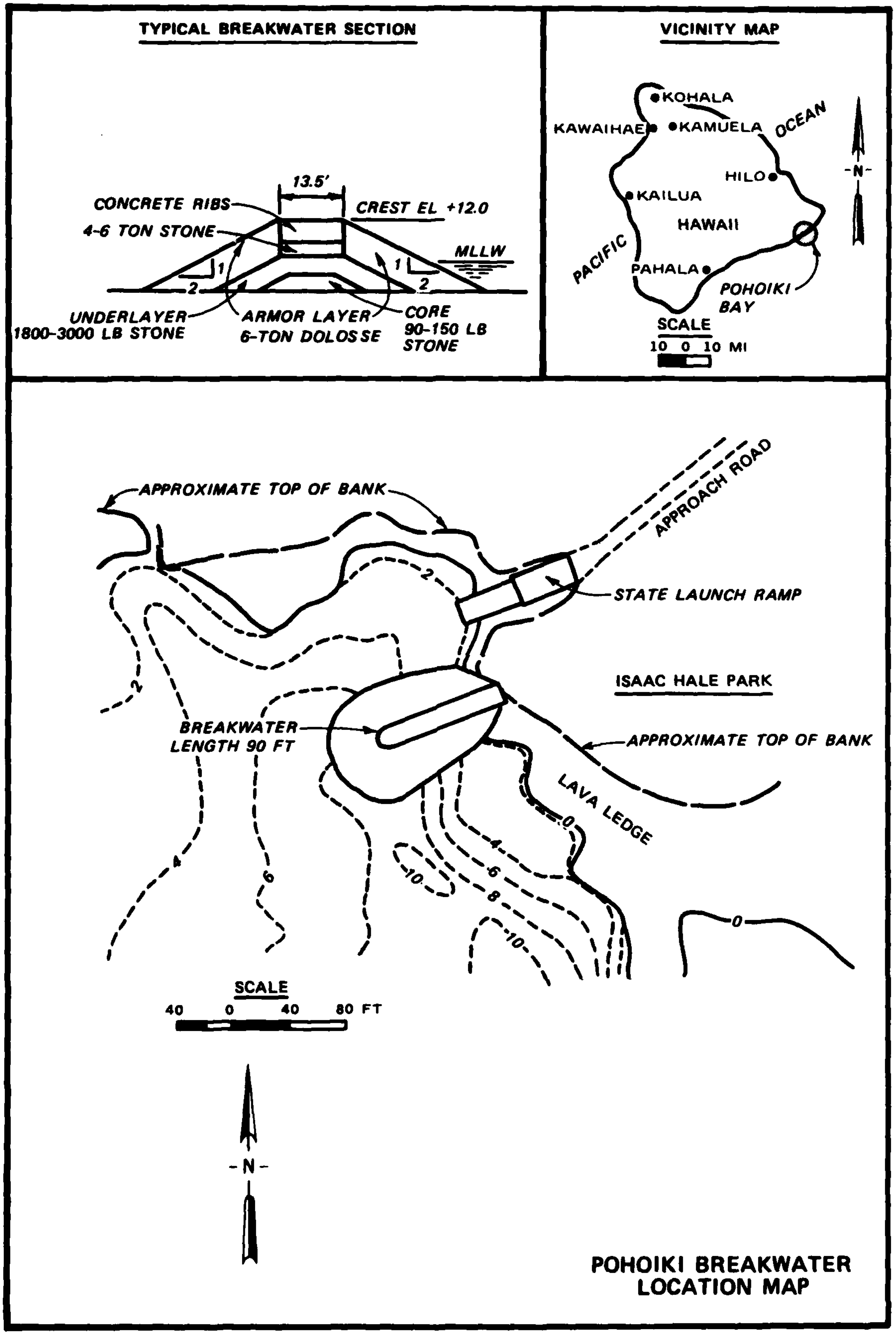
CONCRETE PARAPET
CONCRETE PLATFORM
EL +14
MLLW
1.5
1
STONE
NORTH AND SOUTH JETTIES CROSS SECTION
OCEAN
20'
CONCRETE MONOLITH
CHANNEL
1.5
1
5
MLLW
STONE
DOLOSSE
NORTH AND SOUTH JETTY HEADS CROSS SECTION
HUMBOLDT JETTIES
LOCATION MAP

PLATE 2

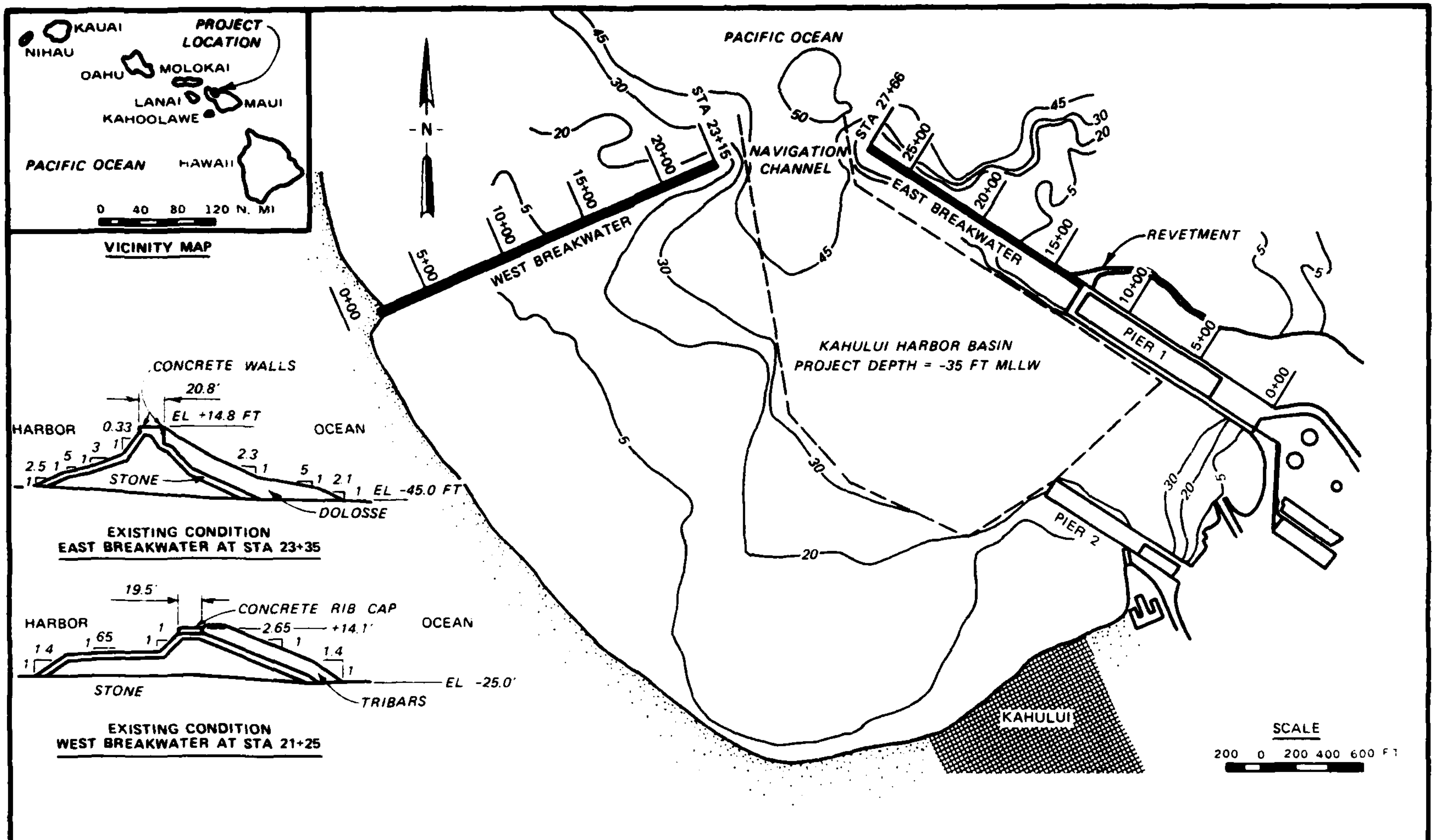


SANTA CRUZ JETTIES
LOCATION MAP

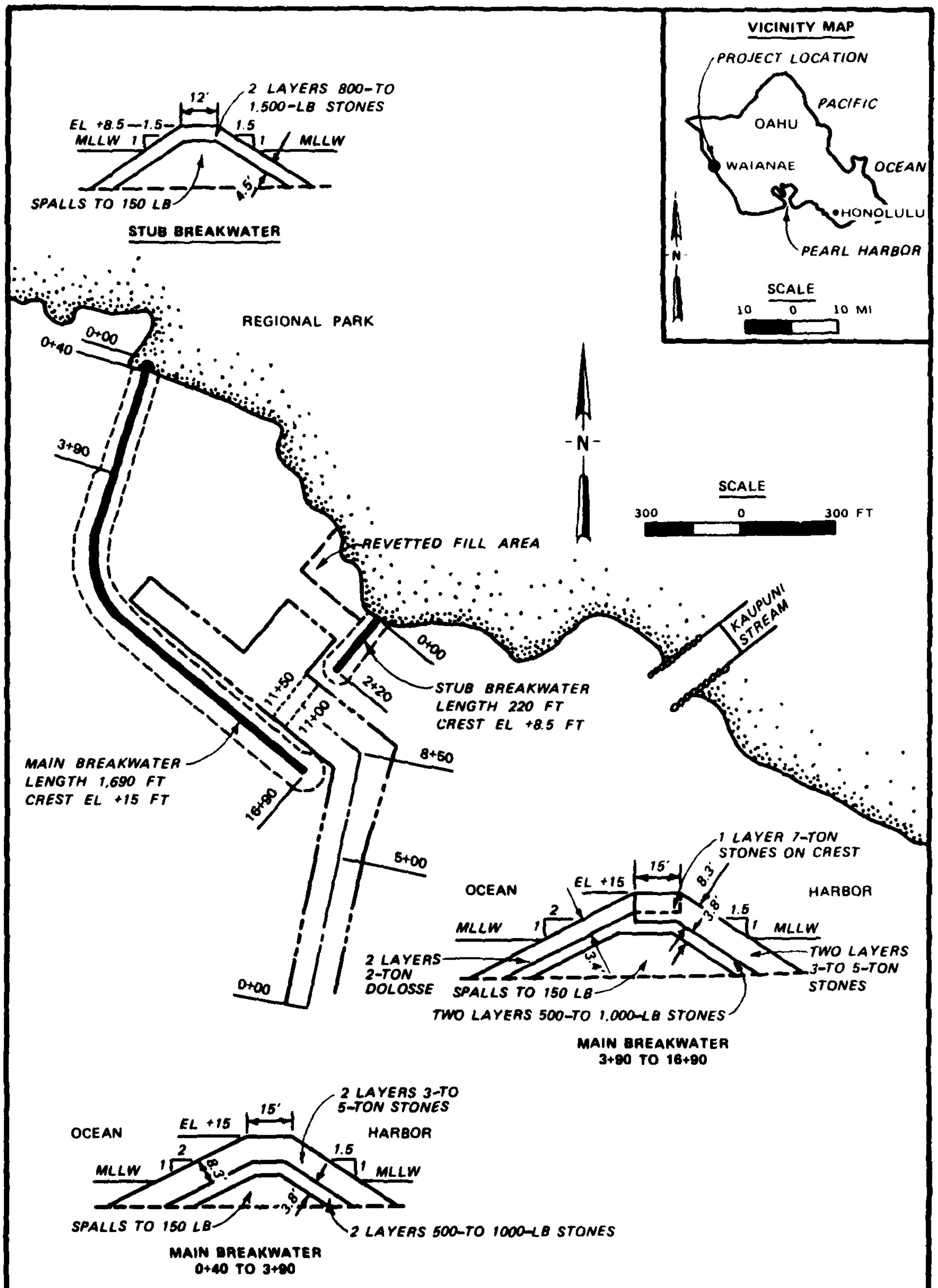


TYPICAL BREAKWATER SECTION
13.5'
CONCRETE RIBS
CREST EL +12.0
4-6 TON STONE
MLLW
1
2
1
2
UNDERLAYER
1800-3000 LB STONE
ARMOR LAYER
6-TON DOLOSSE
CORE
90-150 LB
STONE
VICINITY MAP
KOHALA
KAWAIHAE
KAMUELA
OCEAN
HILO
KAILUA
HAWAII
PACIFIC
PAHALA
POHOIKI
BAY
SCALE
10 0 10 MI
N
APPROXIMATE TOP OF BANK
APPROACH ROAD
STATE LAUNCH RAMP
ISAAC HALE PARK
BREAKWATER
LENGTH 90 FT
APPROXIMATE TOP OF BANK
LAVA LEDGE
SCALE
40 0 40 80 FT
N
POHOIKI BREAKWATER
LOCATION MAP

PLATE 4

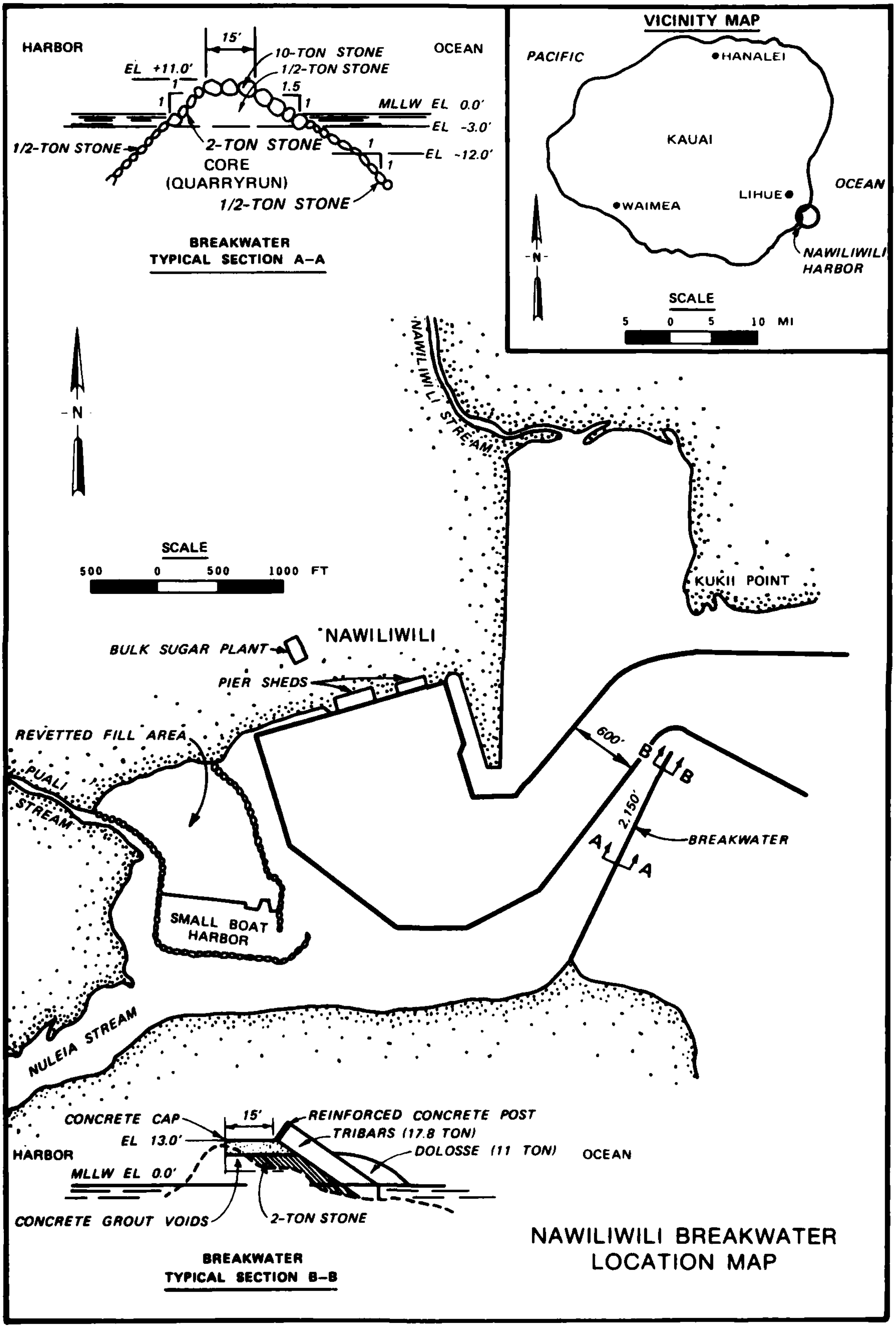


KAHULUI BREAKWATERS
LOCATION MAP



WAIANAE BREAKWATER
LOCATION MAP

PLATE 6


HARBOR
15'
10-TON STONE
1/2-TON STONE
OCEAN
EL +11.0'
1
1.5
1
MLLW EL 0.0'
EL -3.0'
1/2-TON STONE
2-TON STONE
1
EL -12.0'
CORE
(QUARRYRUN)
1/2-TON STONE
BREAKWATER
TYPICAL SECTION A–A
VICINITY MAP
PACIFIC
HANALEI
KAUAI
OCEAN
LIHUE
WAIMEA
NAWILIWILI HARBOR
N
SCALE
5 0 5 10 MI
NAWILIWILI STREAM
N
SCALE
500 0 500 1000 FT
KUKII POINT
NAWILIWILI
BULK SUGAR PLANT
PIER SHEDS
REVETTED FILL AREA
PUALI STREAM
600'
B
B
2,150'
BREAKWATER
A
A
SMALL BOAT HARBOR
NULEIA STREAM
CONCRETE CAP
15'
REINFORCED CONCRETE POST
EL 13.0'
TRIBARS (17.8 TON)
HARBOR
DOLOSSE (11 TON)
OCEAN
MLLW EL 0.0'
CONCRETE GROUT VOIDS
2-TON STONE
BREAKWATER
TYPICAL SECTION B–B
NAWILIWILI BREAKWATER
LOCATION MAP

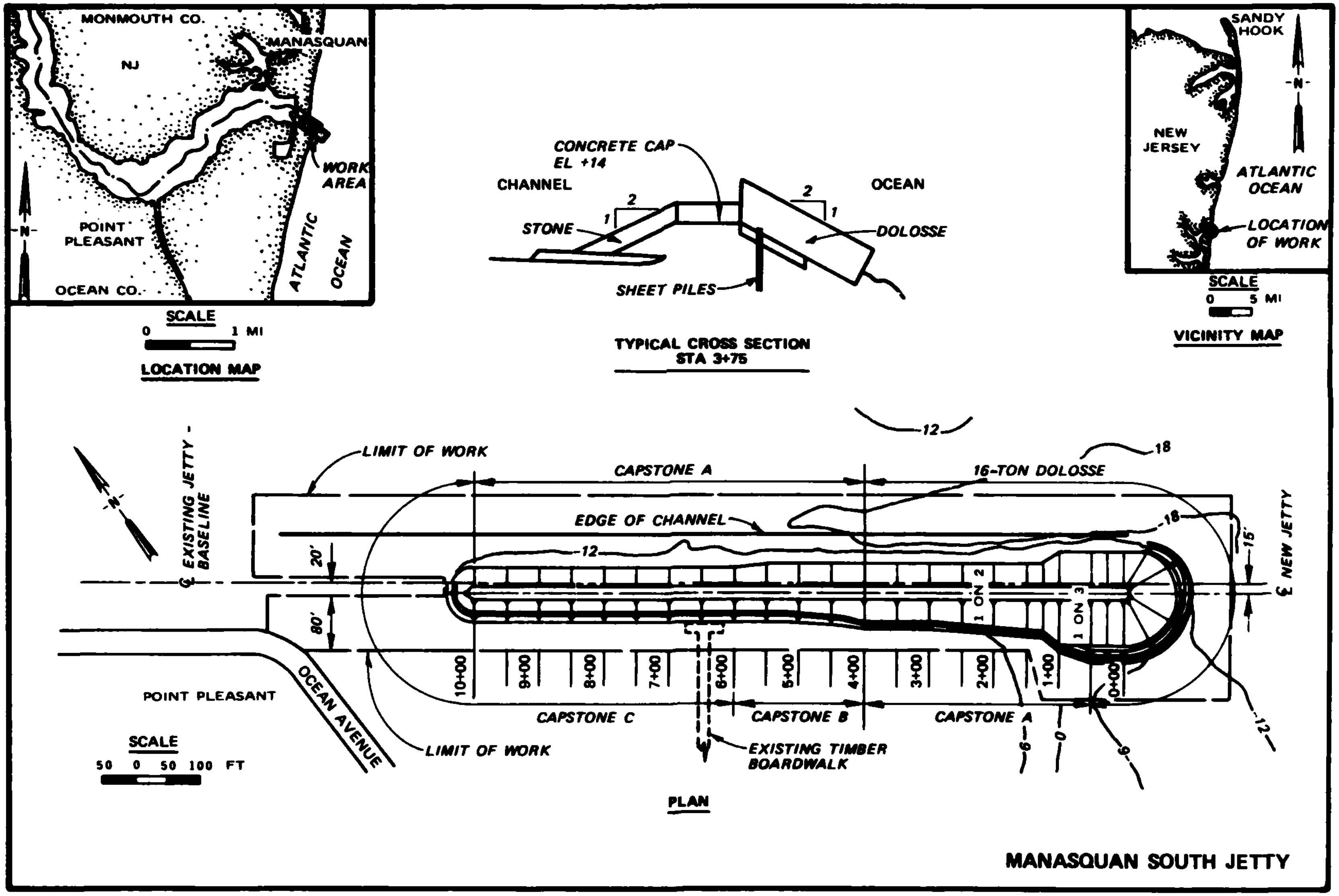
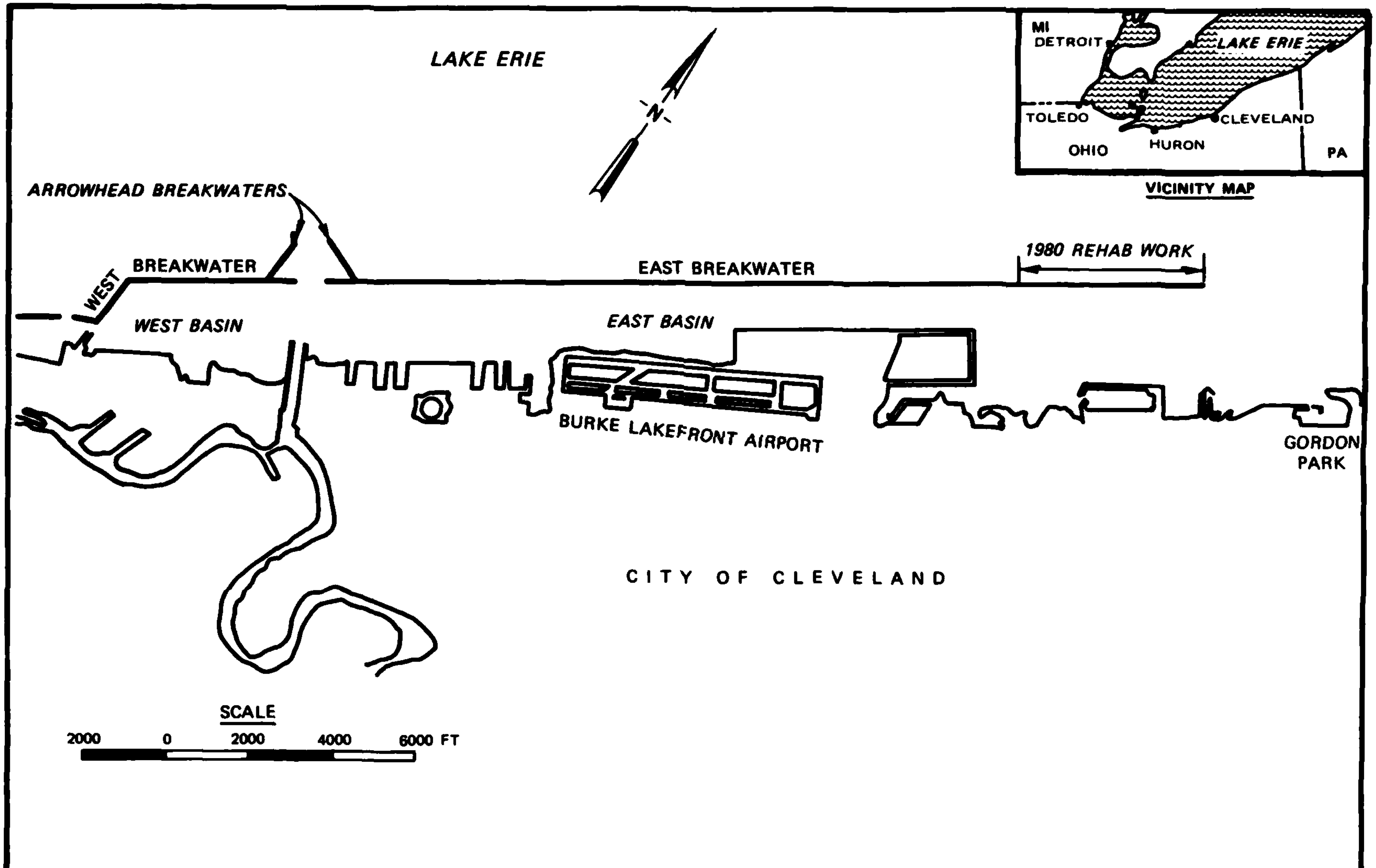
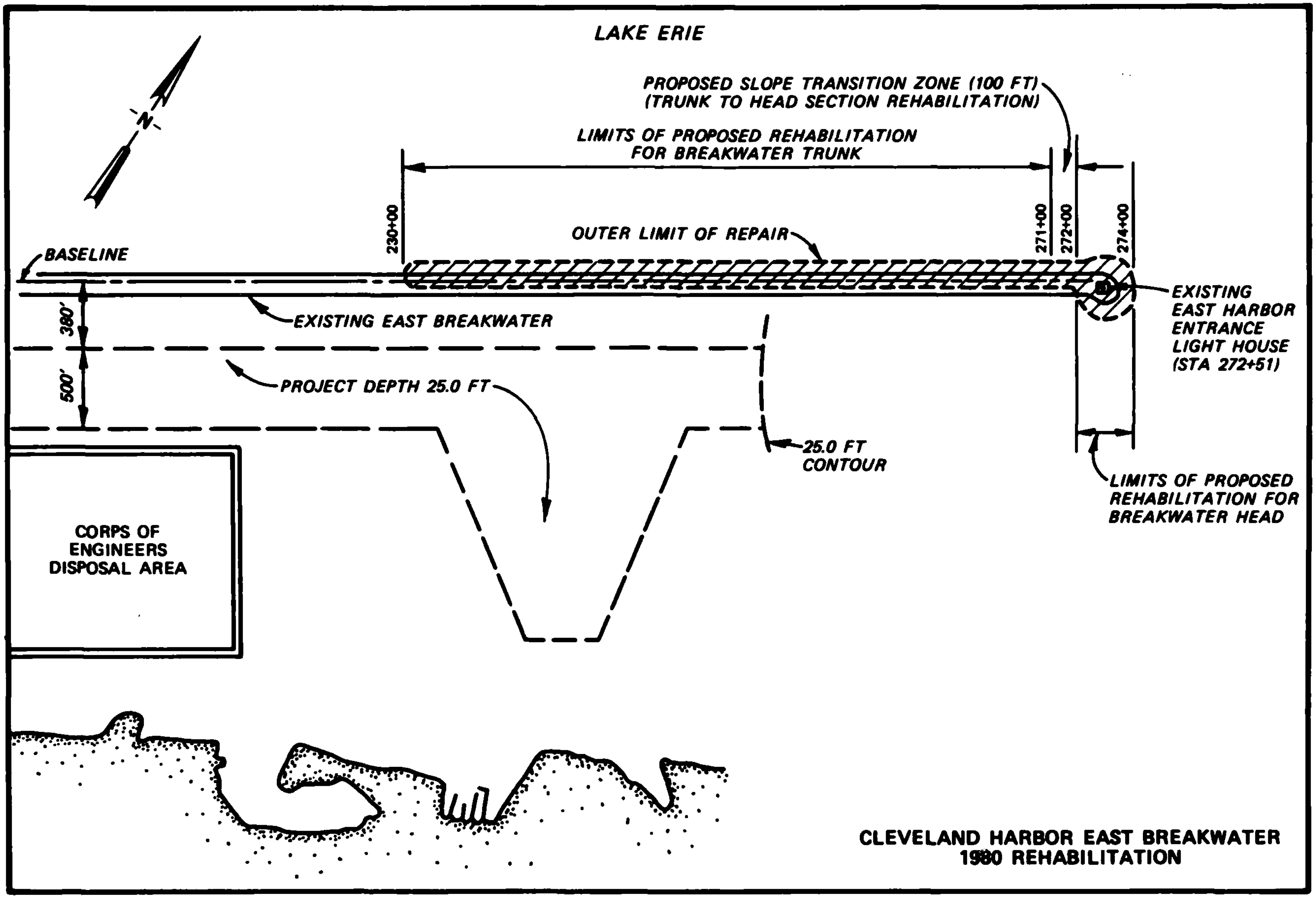

MONMOUTH CO.
NJ
MANASQUAN
WORK AREA
POINT PLEASANT
OCEAN CO.
ATLANTIC OCEAN
N
SCALE
0 1 MI
LOCATION MAP
CONCRETE CAP EL +14
CHANNEL
OCEAN
STONE
DOLOSSE
SHEET PILES
TYPICAL CROSS SECTION STA 3+75
SANDY HOOK
NEW JERSEY
ATLANTIC OCEAN
LOCATION OF WORK
SCALE
0 5 MI
VICINITY MAP
LIMIT OF WORK
CAPSTONE A
16-TON DOLOSSE
EDGE OF CHANNEL
℄ EXISTING JETTY - BASELINE
℄ NEW JETTY
20'
80'
15'
1 ON 2
1 ON 3
10+00
9+00
8+00
7+00
6+00
5+00
4+00
3+00
2+00
1+00
0+00
POINT PLEASANT
OCEAN AVENUE
CAPSTONE C
CAPSTONE B
CAPSTONE A
LIMIT OF WORK
EXISTING TIMBER BOARDWALK
SCALE
50 0 50 100 FT
PLAN
MANASQUAN SOUTH JETTY

PLATE 8



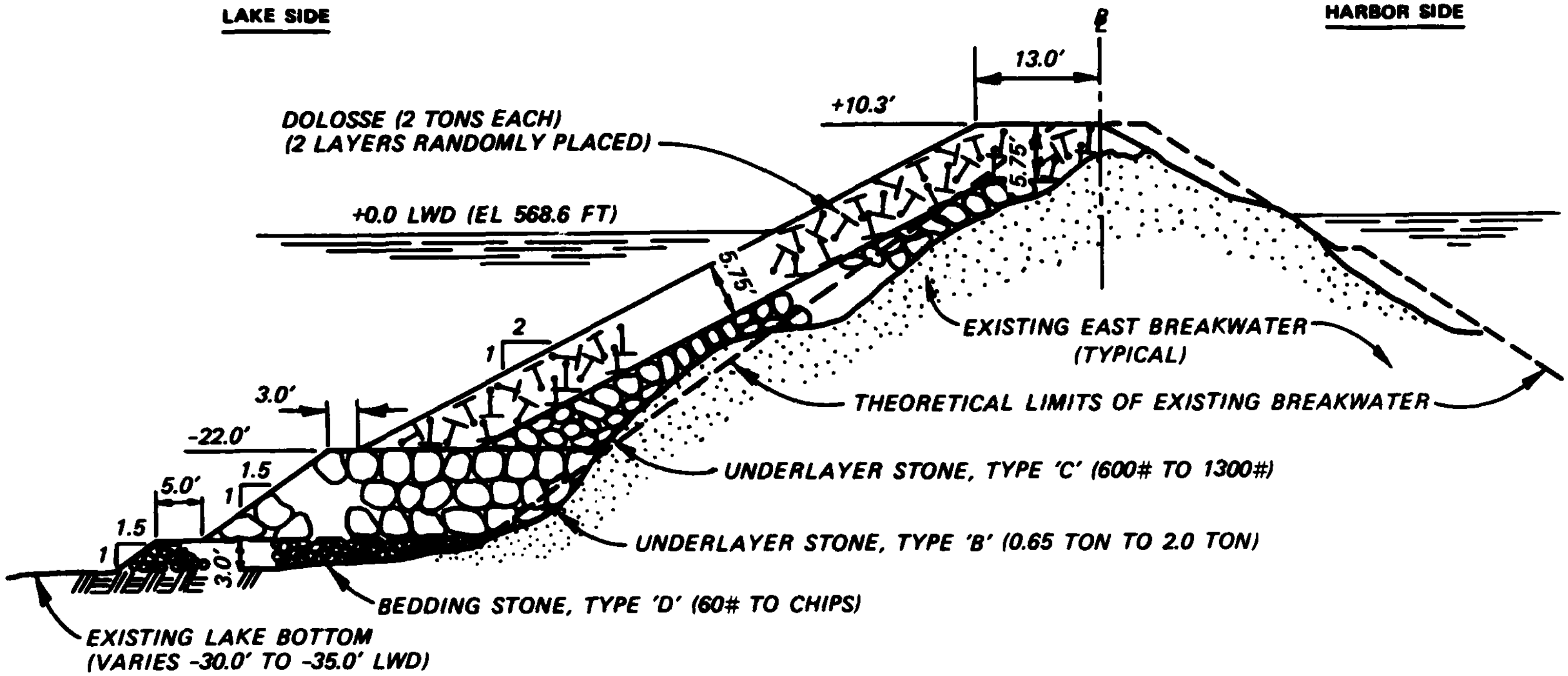
CLEVELAND BREAKWATERS
LOCATION MAP

PLATE 9



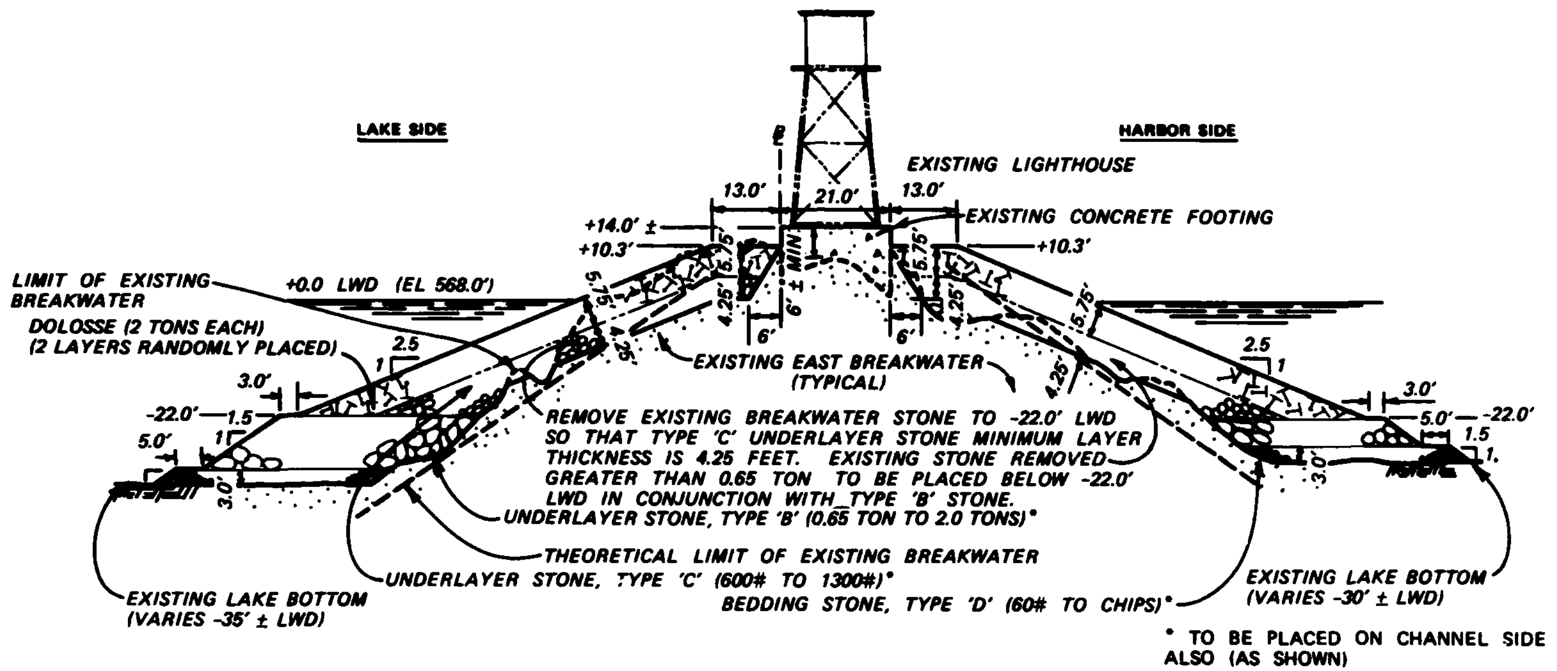
CLEVELAND HARBOR EAST BREAKWATER
1980 REHABILITATION

PLATE 10



SECTION OF BREAKWATER TRUNK

CONCRETE ARMOR UNIT DESIGN,
BREAKWATER TRUNK
(CLEVELAND HARBOR EAST BREAKWATER
1980 REHABILITATION)



SECTION OF BREAKWATER HEAD

CONCRETE ARMOR UNIT DESIGN,
BREAKWATER HEAD
(CLEVELAND HARBOR EAST BREAKWATER
1980 REHABILITATION)

PLATE 12

Appendix A: Questionnaire

SUBJECT: Rubble-Mound Breakwaters and Jetties

1. DIVISION: ____________________ 2. DISTRICT: ____________________

3. STRUCTURE LOCATION: Latitude __________; Longitude ______________;
   State ____________; City ____________________;
   Harbor, Bay, Lake, etc. ____________________.

4. DATE CONSTRUCTED: ______________________________.

5. HAS THE STRUCTURE BEEN EXTENDED IN SIZE SINCE ORIGINAL CONSTRUCTION? Yes No (circle one)

6. IF ANSWER IS YES, PLEASE GIVE DATE OR DATES OF ADDITIONAL CONSTRUCTION. ______________________________.

7. WAS THE STRUCTURE MODEL-TESTED? Yes No (circle one)

8. IF MODEL-TESTED, BY WHOM? ______________________________.

9. NAME AND/OR IDENTIFYING NUMBER OF MODEL-TEST REPORT. ______________ ______________________________.

10. TYPE OF STRUCTURE: (circle appropriate item(s): a. Breakwater, b. Jetty, c. Overtopping, d. Nonovertopping, e. Other (specify) ______________________________.

11. PURPOSE OF STRUCTURE: (circle appropriate item(s): a. Harbor Protection, b. Channel Control, c. Shoreline Erosion Control, d. Other (specify) ______________________________.

12. DESIGN STORM CONDITIONS:
    a. Breaking or Nonbreaking Waves (circle one)
    b. Wave Period(s): ____________________ sec.
    c. Wave Height(s): ____________________ ft.
    d. Water Depth(s) at Structure Toe: ______________________________ ft.
    e. Storm's Frequency of Occurrence (circle one):
       1. 1 in 10 years
       2. 1 in 25 years
       3. 1 in 50 years
       4. 1 in 100 years
       5. Other (specify): 1 in __________ year(s)
    f. Storm Duration: ______________ hr

13. STRUCTURE CHARACTERISTICS:

a. Datum Base: (circle one) MSL; MLW; MLLW; LWD; PBD; Other (specify) ________________; b. Crown Elevation ____________________;
c. Crown Width ______________________; d. Sea-Side Toe Elevation ________________; e. Beach-Side Toe Elevation _________________;
f. Side Slopes: Sea Side 1V: ________H; Beach Side 1V: ___________H;
g. Was a Crown Wall Used? Yes No (circle one)
h. If Answer is Yes, Please Give a Brief Description (size, material, construction methods, etc.): ______________________________
____
____.
i. Total Structure Length: ____________________________________.

14. ARMOR PROTECTION:

a. Type: (circle one) 1. Stone 2. Dolosse 3. Tribars
4. Tetrapods 5. Blocks 6. Other (specify) ___________________.
b. Type of Placement: (circle one) 1. Random 2. Uniform
3. Special 4. Other (specify) ______________________________.
c. If Some Special Placement Technique, Please Give a Brief Description: ____
____
____.
d. Number of Armor Layers: (circle one) 1 2 Other (specify) ____.
e. Weight of Individual Armor Units: ___________________________.
f. Number of Armor Units Placed: ______________________________.
g. Where Were the Armor Units Placed: (describe briefly) - (For Example: From sea-side toe, over crown to -6.0 ft MSL on beach-side slope). ____
____.
h. If Molded Concrete Armor Units Were Used, Was Any Type of Reinforcement Used? Yes No (circle one)

i. If Answer Was Yes, What Type of Reinforcement Was Used?
(circle one) 1. Steel 2. Stainless Steel 3. Other (specify)
____.

15. UNDERLAYERS AND CORE:

a. Number of Underlayers: (circle one) 0, 1, 2, 3, Other _______.

b. Weight Range of Material Used in Each Underlayer:
1st Layer _________; 2nd Layer _________; 3rd Layer _____________.

c. Thickness of Each Underlayer:
1st Layer _________; 2nd Layer _________; 3rd Layer _____________.

d. Weight Range of Core Material: ____________________________.

16. OBSERVATIONS:

a. If Molded Armor Units Were Used, Did Any Cracking or Breaking of Units Occur During Construction? Yes No (circle one)

b. Were These Cracked or Broken Units Left on the Structure?
Yes No (circle one). If Yes, How Many? ______________________.

c. What Are the Maximum Storm Conditions that the Structure Has Been Exposed to Since Construction Was Completed?
1. Wave Period: _________ sec; 2. Wave Height: _____________ft;
3. Storm Surge Level: ____________________; 4. Storm Duration:
______________hr; 5. Date of Storm: ____________________mo/yr.

d. To Date, Has the Structure Accrued Any Damage? Yes No (circle one). If Yes, What Type of Damage? (circle appropriate item(s):
1. Crown Lowering
2. Armor Unit Displacement
3. Armor Unit Breakage
4. Other (specify) ____________________________________
____.

e. If Armor Unit Breakage Has Occurred, What Was (or Is) the Total Number Broken? ____.

f. Out of this Total Number Broken, How Many Are (or Were) on the:
Beachside Above the Water? ______________________________.
Beachside Below the Water? ______________________________.
Seaside Above the Water? ________________________________.
Seaside Below the Water? ________________________________.

SUBJECT: Rubble-Mound Breakwaters and Jetties (concluded)

g. Was (or Is) the Breakage Concentrated in the: (circle appropriate item(s): 1. Top Layer

2. Bottom Layer

3. Both Layers

h. Was (or Is) the Breakage: (circle appropriate item):

1. Spread Randomly over Entire Structure.

2. Concentrated in Certain Areas: (specify) ______________________

____.

i. Has Any Toe or Slope Instability Occurred due to Scour Along the Structure Toe? (circle one) Yes No Unknown

j. If the Structure Has Been Damaged, Have Repairs Been: (circle appropriate item) 1. Completed (Date ________________ mo/yr).

2. Started (Date ____________________ mo/yr).

3. Planned for Future (Date ______________).
year

4. Ruled Out Entirely.

k. If the Structure Had (or Has) Broken Armor Units, During its Repair, Were (or Will) the Broken Units (Be) Removed During the Rehabilitation of the Structure? (circle one) Yes No

l. If Available, Please Furnish or Give Name and Address of the Source(s) Where the Following Items Can Be Found:

1. Design and Construction Drawings.

2. Construction and Inspection Photos.

3. Aerial Photos or Plan Drawing Showing the Alignment and Location of the Structure Relative to the Shoreline.

4. Design Report.

5. Inspection Reports.

END

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